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DIFFERENTIAL DECOMPOSITION RATES OF NON-HUMAN REMAINS WITH THE FACILITATION OF SODIUM HYDROXIDE IN DISSIMILAR DEPOSITION ENVIRONMENTS

Hayley Savage
University of Montana, Missoula

DIFFERENTIAL DECOMPOSITION RATES OF NON-HUMAN REMAINS WITH THE FACILITATION OF SODIUM HYDROXIDE IN DISSIMILAR DEPOSITION ENVIRONMENTS

By

HAYLEY ELIZABETH JOYCE SAVAGE

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Approved by:

Scott Whittenburg, Dean of The Graduate School
Graduate School

Dr. Randall R. Skelton, Chair
Anthropology

Dr. Kirsten Green
Anthropology

Dr. Christopher Palmer
Chemistry

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Differential Decomposition Rates of Non-Human Remains with the Facilitation of Sodium Hydroxide in Dissimilar Deposition Environments

Chairperson: Dr. Randall R. Skelton

Abstract:
Dissolving bodies is a contemporary method of disposing human remains and has been practiced throughout the years. In popular media, criminals attempt to dispose of their victims by using various chemicals to dissolve the corpses. There is an immense gap in the literature pertaining to this research, so this present study aims to combat the lack of information on the topic. This research investigates the effects of sodium hydroxide (NaOH), generally known as lye or caustic soda, a common household chemical, on human tissues and bone by using an animal analogue (domestic pig, *Sus scrofa domesticus*). Four dissimilar deposition environments were tested during this study to determine the differential decomposition rates while exposed to sodium hydroxide. Over time, the appearance, consistency and temperature of all specimens were documented. After 60 days, the specimens were removed from their respective totes so various analyses could be performed on the remaining tissues. Numerous results were observed, but most notably one of the pigs underwent substantial decomposition, while the other three specimens did not. These results demonstrate how the combination of different deposition environments and the facilitation of sodium hydroxide can have diverse effects on tissue, skin, bone, nails and hair.

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Table of Contents

Acknowledgements ***iii***

List of Figures ***v***

List of Tables ***vi***

Chapter 1 – Introduction **1**

Chapter 2 – Literature Review **5**

Effects of Household Chemicals on Human Dentition 6

Effects of Household Chemicals on Human Tissue, Bone and Nails 9

Microscopic Residues from Dissolving Human Remains in Acids 11

"Detergent Suicides" 14

Effects of Soil pH on Human Tissue and Bone 16

Insect Contact with Human Tissue 17

Chapter 3 – Hypotheses and Expectations **20**

Hypotheses 20

Expectations 20

Chapter 4 – Materials and Methods **22**

Indoor Specimens 23

Outdoor Specimens 26

Chapter 5 – Results **29**

Indoor Specimens 29

Bone Consistency Test *37*

Outdoor Specimens 37

Tissue Texture Test *42*

Bone Analysis 42

Tibia and Fibula *43*

Calcaneus, Astragalus and 4th Metatarsal *45*

Chapter 6 – Discussion **48**

Chapter 7 – Conclusion **54**

References Cited **55**

Appendix **59**

List of Figures

4.1	Lye used in this study	22
4.2	Pig A before experiment commenced	24
4.3	Pig C before experiment commenced	24
4.4	Tote A on Day 1	25
4.5	Tote C on Day 1	25
4.6	Pig B before experiment commenced	27
4.7	Pig D before experiment commenced	27
4.8	Tote B on Day 1	28
4.9	Tote D on Day 1	28
5.1	Pig A on Day 13	30
5.2	Close-up of Pig A showing solidified fat	31
5.3	Pig A on Day 45	31
5.4	Close-up of Pig A showing marbling	32
5.5	Pig A on Day 60	32
5.6	Pig C on Day 3	34
5.7	Close-up of Pig C showing break in skin	34
5.8	Pig C on Day 11	35
5.9	Pig C on Day 21	35
5.10	Pig C on Day 45	36
5.11	Close-up of Pig C showing unidentifiable foot	36
5.12	Pig C on Day 60	36
5.13	Pig B on Day 5	38
5.14	Pig D on Day 5	39
5.15	Foot of Pig B on Day 11	39
5.16	Foot of Pig D on Day 11 showing skin sloughing	40
5.17	Pig B on Day 60	40
5.18	Pig D on Day 60	41
5.19	Pig B on Day 60, side exposed to lye	41
5.20	Pig B on Day 60, side not exposed to lye	41
5.21	Pig D on Day 60, side exposed to lye	41
5.22	Pig D on Day 60, side not exposed to lye	41
5.23	Close-up of tibia of Pig C showing flaking	44
5.24	Tibia of Pig C showing cracking	44
5.25	Close-up of tibia of Pig C showing porosity	44
5.26	Close-up of fibula of Pig C showing flaking	44
5.27	Close-up of fibula of Pig C showing integrity of cortical bone	44
5.28	Calcaneus of Pig C showing cracking	46
5.29	Calcaneus of Pig C showing modified trabecular bone	46
5.30	Astragalus of Pig C showing cracking	47
5.31	Astragalus of Pig C showing modified trabecular bone	47
5.32	4^{th} metatarsal of Pig C showing cracking	47
5.33	4^{th} metatarsal of Pig C showing lack of cortical bone and modified trabecular bone	47

List of Tables

1	Test results of the effects of sodium hydroxide on rabbits and mice	21
2	Experiment information	23
3	Decomposition Staging Scale	49

Chapter 1 – Introduction

Attempts to hide the identity of a victim(s) and prevent positive identification(s) are frequent, and may include dismemberment, destruction or removal of teeth, disfigurement of the face, removal of fingers to hinder identification through matching fingerprints, burning of the body and even dissolution in various household chemicals. However, many different techniques are used to obtain a positive identification of human remains and use more than one type of tissue to do so. Therefore, there really is no way to conceal a homicide, but that does not stop perpetrators from attempting to do so. Household corrosive substances that may be used to disfigure a body include easily obtainable constituents, such as drain cleaners, landscaping materials, septic tank cleaners, pool chemicals, rust dissolvers, and other various cleaning products (Hartnett et al., 2011). Because methods of positive identification involve both soft and hard tissues, scientists must strive to understand how corrosive agents affect all the various types of tissue that compose the human body.

Unfortunately, there is an immense gap in the literature concerning the chemical effects that household products may produce on human remains. Only when do executioners try to dispose of a victim with highly acidic or basic substances does the matter become intriguing to the public. Due to the lack of publications pertaining to a methodological approach for analyzing skeletal remains exposed to corrosive substances, forensic scientists may not be able to identify the chemicals used on victims' corpses or how different chemicals have varying effects on human remains. Unfortunately, published forensic cases only hint at the utilization of chemicals for intentional destruction of individuals and the chemical effects on the human skeleton.

Nonetheless, an understanding of how different chemicals affect the human body is crucial, especially for investigating forensic cases.

The remains of three individuals were recovered from three separate 50-gallon metal drums in a desert area west of Phoenix, Arizona. Based on the condition of the bodies, the use of an unknown corrosive chemical to obscure the identities of the individuals was suspected by investigators working on the case. Multiple white plastic safety seals that are commonly used to secure containers of destructive substances were found in juxtaposition with each of the decedents. The large number of safety seals suggested the use of a chemical agent that was easily acquirable by the perpetrator. Two of the three individuals were nearly completely consumed by the agent, while one had extensive disfiguring of the soft tissue and skeleton consistent with some type of corrosive substance. Various studies attempted to determine the possible agent used, and those studies were later expanded to test a multiplicity of corrosive agents and their effect on human bone and tissue (Hartnett et al., 2011).

Another instance of dissolving bodies in a corrosive substance is one of history's most notorious cases which involved the "Acid Bath Murderer", John George Haigh, an English serial killer during the 1940's, was convicted and subsequently executed for murdering six people. He dissolved the bodies in concentrated sulfuric acid, thinking that if his victims' bodies could not be found or identified, then a murder conviction would not be possible. Notwithstanding the absence of his victims' bodies, the substantial forensic evidence was sufficient for Haigh to be condemned for the murders. Although the acid had destroyed a great deal of evidence, not everything had been completely disintegrated from a forensic perspective. As the forensic team examined the acidic greasy soil where the individuals were dumped, they found the following items: twenty-eight pounds of human body fat, three faceted gallstones, eighteen fragments of

human bones (of which eleven were identified), part of a left foot, and intact upper and lower dentures. To test the effectiveness of sulfuric acid to dissolve human remains, a series of experiments were carried out at the Metropolitan Police Forensic Science Laboratory in London, England. A defleshed sheep's femur took four days to dissolve, an amputated human foot, however, dissolved completely in only four hours. According to the investigators, the heat generated by the interaction of acid and the amount of water present in the flesh surrounding the bones of the foot was the vital factor in the increased effectiveness of the acid (Hartnett et al., 2011).

When lye is heated to approximately 300°F, the solution can turn a body into a tan liquid with a viscous consistency in just three hours. However, conditions must be ideal. If the containers are not pressurized, it would be impossible to heat the solution much above the boiling point of water 212°F, and it might take additional time to complete the process (Palmer, 2009). The pioneer of this technique, Adolph Louis Luetgert, known in his day as the "Sausage King of Chicago", was a German-American charged with murdering his wife and dissolving her body in lye in one of his sausage vats at the A.L. Luetgert Sausage & Packing Company in 1897.

Nowadays, most bodies are liquefied using this technique for legitimate reasons. Some universities use industrial digesters to dispose of cadavers used for research and medical education. The machine, which looks like a giant pressure cooker, mixes about 70 gallons of water with a small amount of lye. When the cycle is complete, the liquefied remains are safe to pour down the drain. A perforated basket catches the solids that survive the process, including implanted medical devices; the pieces left can be disposed of or crushed into a fine white powder (Palmer, 2009). However, there are still circumstances where criminals will try to dispose of their victim's bodies through the use of corrosive substances, the present study aims to examine

those effects in order to aid in the identification of what chemical could have been used, and to aid in a positive identification of the victim.

This research investigates the effects of sodium hydroxide (NaOH), commonly known as lye or caustic soda, a common household chemical, on human tissues and bone by using an animal analogue (domestic pig, *Sus scrofa domesticus*). The main objective of this study is to provide a contemporary understanding of how a readily available household chemical can grossly affect the decomposition process. This understanding will aid tremendously in forensic investigations in which corrosive chemicals are used to expedite the decomposition process of disparate perpetrators' victims.

Chapter 2 – Literature Review

Much of the research carried out on corrosive agents on human tissue has come from studies done on human dentition. Those studies are mostly from medical and dental studies of bulimia, workplace safety and restorative dentistry (Hartnett et al., 2011; Tuominen et al., 1989). Few publications describe the effects of chemicals on the human skeleton, dentition and skin. However, some exceptions include the analysis of the Romanovs by Maples (1994) and King and Wilson (2003), in which dental remains, skeletal remains and soil samples suggested exposure to a corrosive agent. Later, interviews of the offenders revealed that sulfuric acid was likely the corrosive agent used to mask their identity. A study by Ubelaker and Sperber (1988) described a case where dental fragments were damaged by a chemical agent tentatively identified as sodium hydroxide. Skeletal remains were discovered in an unused cistern near the Omaha, Nebraska airport and were positively identified through comparison of antemortem and postmortem dental radiographs. Although nearly nine years had elapsed between the death and discovery, the bones and teeth revealed evidence of the application of a corrosive substance at or around time of death, as well as an unusual restricted response to sun exposure, that contributed to the prosecution and murder conviction of a member of the Hell's Angels in the Omaha area (Ubelaker and Sperber, 1988).

Until a more recent study by Cope and Dupras (2009) on the effects of household corrosive chemicals on human dentition, no published studies quantified the destruction of human tissues caused by corrosive agents. Cope and Dupras exposed sixteen human teeth to a total of eight readily available household products, each containing different concentration of sulfuric acid, phosphoric acid, hydrochloric acid and sodium hydroxide. After each tooth was

submerged in the various chemicals, both quantitative and qualitative descriptions were recorded at regular intervals (Cope and Dupras, 2009). This chapter will investigate various literature that discusses the diverse effects corrosive chemicals have on human skin, muscle, hair, nails, and dentition, while also exploring other topics such as soil pH and insect contact with human bone.

Effects of Household Chemicals on Human Dentition

A variety of techniques are used to ascertain a positive identification of human skeletal remains, however, one of the most common methods is the comparison of antemortem and postmortem dental records. The corroboration of the records depends on identifying characteristics, such as any type of dental work or defining structures of the teeth. Human dentition has a longstanding presence, even after deterioration of all other soft tissue and bone, making the remains of dental fragments very important parts of archaeological and forensic human remain analysis. There are several potential contexts in which human teeth may be exposed to corrosive agents: the act of vomiting in bulimic individuals, forensic cases involving the use of corrosive chemicals on a victim, industrial chemical hazards in the workplace and methods in dentistry, which regularly expose teeth to acidic chemicals (Cope and Dupras, 2009; De Moor, 2004; Newton and Travess, 2000, Rytömaa et al., 1998).

Cope and Dupras collected forty-one human teeth from a dentist in Orlando, Florida, and sixteen of those teeth were chosen because of their overall completeness and lack of pathology. Many of those teeth have calculus buildup and cavities, which represent real-world dental conditions. Of the eight chemicals used in the experiment, seven products were purchased at general stores and one chemical was prepared by dissolving sodium hydroxide pellets. The corrosive chemical categories the authors used include: sulfuric acid, hydrochloric acid,

phosphoric acid and sodium hydroxide. The actual chemical products the authors used include: Smart Products® pH Decreaser, Sno Bol® Liquid Disinfectant, Floweasy® Drain Opener, Rooto® Professional Drain Opener, PH-OSPHO-RIC Plus, Naval Jelly® Brand Rust Dissolver, Roebic® Professional Strength Liquid Drain Opener and dissolved sodium hydroxide pellets. Two products were assigned to each chemical category, with the first product demonstrating a higher concentration of the caustic chemical and the second product demonstrating a lower concentration. An incisor and molar were selected for each chemical group. Quantitative data and qualitative data were documented throughout the experiment; the quantitative data included measurement of the crown width, tooth length and weight (Cope and Dupras, 2009).

The results of that experiment showed that products containing hydrochloric acid can produce severe dissolution of dentition and are thus able to eradicate crucial evidence on teeth, such as unique features that are important in attaining a positive identification of a victim or trauma. Exposure to hydrochloric acid results in two characteristics: rapid removal of the enamel and a subsequent jelly-like consistency. Cope and Dupras conclude that hydrochloric acid is the most detrimental acid in the dissolution of dentition; the results from Mazza et al. (2005) yielded consistencies with Cope and Dupras' analyses. Other resulting effects, such as the etching and erosion of the enamel and overall thinning of the tooth, is conclusive with the consequences often witnessed with patients of bulimia nervosa; these are also reported effects of individual's teeth who work in proximity with chemicals daily. However, there is clear difference in those cases, because of the pattern and location of occurrence. Therefore, confusion should not occur during forensic analyses with intentional use of corrosive chemicals versus bulimia or workplace results.

Sulfuric acid caused minor changes to the tooth structure, although the acid did cause etching of the enamel, similar to that reported in the Romanov case (Maples and Browning, 1994). Variations in sulfuric acid concentration and the longer exposure time experienced by workers in proximity to the acid can account for the lack of discernible changes in the current experiments. The pasty consistency of the enamel caused by sulfuric acid is likely due to the loss of inorganic material of the tooth. Similarities were observed with the phosphoric acid, which also produced a pasty effect on the enamel, but at a much higher degree. The phosphoric acid had variable harmful effects on the teeth. The morphological effects of hydrochloric acid and phosphoric acid on dentition are similar in the eradication of the enamel, but there are clear distinctions on how each agent alters the enamel portion. Sodium hydroxide provided no distinguishable reactions with the organic or inorganic properties of the enamel that was observed with the acids. Interestingly, Ubelaker and Sperber (1988) identified sodium hydroxide as the responsible chemical in a case involving human remains, and the effects observed in Cope and Dupras' study contradicts Ubelaker and Sperber's. However, the case of Ubelaker and Sperber involves a different situational context (environmental effects and the manner and amount of the chemical used), and as such the teeth may have also been affected by these factors (Cope and Dupras, 2009).

Variations in the morphological effects support Cope and Dupras' initial hypothesis, that each chemical creates morphological changes on teeth that are uniquely characteristic for that chemical. The comparable data can be quite useful when dealing with forensic cases that show evidence of chemical corrosion on human dentition. An understanding of the unique effects caused by readily available household chemicals on human teeth may lead to the identification of various chemical agents utilized on a victim. Such an understanding can only be of value to the

forensic field, not only in establishing the identity of a destructive chemical, but also in providing leads on criminal intent, differentiating taphonomic processes, providing substantiation of a criminal's confession, and hopefully providing a positive identification of victims that are affected by this (Cope and Dupras, 2009).

Effects of Household Chemicals on Human Tissue, Bone and Nails

The research of Hartnett, Fulginiti and Modica (2011) continued the research carried out by Cope and Dupras, but they extended the experiment to include the effects of common household corrosive agents on human bone, hair, teeth, nails and soft tissue (skin, muscle, fat and fascia). They tested six commonly available chemical substances and a control (tap water). Those chemical substances include: hydrochloric acid, sulfuric acid, household lye, bleach, a 100% natural active bacteria and enzyme product and the Coca-Cola® soft drink. A nonpathological human femur from a European man, forty-nine years of age at death, was purchased from a medical research company by the experimenters for the study. The tissue was procured from the adherent skin, muscle, fascia and connective tissue on the donated femur. The fingernails were obtained from a manicurist and represent cut distal tips. The hair was obtained from a beauty salon and represents cut hair and the teeth were donated by a forensic odontologist (Hartnett et al., 2011).

Hydrochloric acid completely consumed all biological tissue samples, except hair and nails, in twenty-four hours or less. The rate of loss was steady over the course of the experiment; bone was completely dissolved in less than twenty hours, nails were unrecognizable after fourteen days and the hair separated after eight days. Sulfuric acid consumed the bone and the teeth over a period of several days, while making the bone and teeth soft and viscous with

formations on the surfaces when immediately exposed to the acid. The bone was completely dissolved in six to seven days, while the teeth were completely consumed in ten days. Nails were present but unrecognizable as nails after fourteen days, while hair and flesh were consumed in less than five hours. The bone segment and teeth that had been submerged in the bleach remained structurally unchanged after one month. Both the bone and teeth, however, became whiter. The hair was consumed by the bleach in eight minutes, the fingernails in six hours, and the flesh in six hours as well (Hartnett et al., 2011).

When the remains were subjected to lye, the hair dissolved in three minutes and it appeared to dissolve the fat in the flesh sample but did not affect the other tissues. The lye also dissolved the contents of the marrow cavity in the femur sample but did not alter the structure or color of the bone; the teeth remained unchanged. Interestingly, the lye produced an increase in temperature of the contents of each jar. Once the lye was combined with each biological tissue sample, the contents and the jar became too hot to touch with bare hands. The 100% natural active bacteria and enzyme product, that is made to break down biological materials in septic tanks, did not affect any of the tissues tested. Neither the density nor the integrity of the biological samples were altered by the Coca-Cola®, though all the samples became darker in color (Hartnett et al., 2011).

The results of the study conducted by Hartnett et al. (2011) demonstrate that various types of household corrosive substances are capable of damaging and destroying human tissues, and thus could be used to mask or eradicate evidence and features used for identification and trauma analysis. Of the six corrosive agents tested, hydrochloric acid was by far the most destructive and could possibly be used to consume an entire human body. According to Mazza et al. (2005), the amount of acid needed to completely dissolve a body is approximately 80-100

liters. Since hydrochloric acid and sulfuric acid are less expensive than other acids and readily available to consumers, Mazza et al. speculate that they would be the preferred acids to use, should someone want to dispose of a body (Mazza et al., 2005). The conclusions drawn by Cope and Dupras (2009) clearly complement those discovered by Hartnett et al. (2011).

Microscopic Residues from Dissolving Human Remains in Acids

A few studies have been conducted considering the effects of various household corrosive chemicals have on human dentition and tissues, but Vermeij, Zoon, van Wijk and Gerretsen (2015) carried out a study on the microscopic residues of bone from dissolving human remains in acids while exploring two different case studies. During the last decade in the Netherlands, two cases have emerged in which human remains were treated with acid. In the first case, a witness declared that a suspect involved in drug trafficking had killed his missing companion and burned him in an improvised incinerator. However, no remains of either the victim or the incinerator were found, but later during a house search, the police found an off-white concrete-like object speckled with pink and brown spots, buried in a refuse bag in the suspects' garden. Initially, the composition of the item was not known. However, after embedding the white substance in epoxy resin and preparing a polished section of the material in question, its internal structure was revealed. The pink and brown spots consisted of some sand and thin-walled structures containing calcium, fluorine and phosphorus. Because of the odd composition, it was originally thought that the thin-walled structures were bone that had almost completely dissolved by hydrofluoric acid alone or by a mixture of hydrofluoric and other acids. Presumably, the suspect had tried to dissolve the cremated remains in hydrofluoric acid and mixed the residue with gypsum, which is commercially available (Vermeij et al. 2015).

To confirm that hypothesis, a series of experiments was launched in which cremated human remains were exposed to mixtures of acids of different strengths and compositions. Because the suspect was a professional welder, the experiments focused on pickling acid and pickling paste, which contain a mixture of hydrofluoric and nitric acid. The white substance was analyzed further to determine the exact mixture of acids that had been used. Due to the presence of fluorine in the white item, the use of hydrofluoric acid could be determined from the start. It was not clear, though, whether other acids than hydrofluoric acid had been used (Vermeij et al. 2015).

In the second case, a family of five were accused of murdering two men in 2009 and 2011 and dissolving their bodies in acid. A witness declared to the police that he had helped to dispose the bodies by dissolving them in a mixture of hydrochloric and sulfuric acid in a plastic barrel, and then flushing the remaining fluid down the drain. The first victim was violently killed, and then wrapped in plastic and transported to a building with two garages. The wrapped body was frozen and transferred to a plastic barrel in one of the garages, which had a floor that consisted of sand and loam underneath a layer of concrete tiles. The body was completely submerged in a mixture of hydrochloric and sulfuric acid. Soon after the beginning of the breakdown process, the barrel started to leak and the acid trickled through the tiles into the underlying soil. The body was then relocated to the other garage, which had a concrete floor. According to the witness, that floor was heavily damaged by the leaking acid and was repaired afterward. After two weeks, the dissolved body was poured down the drain adjacent to the witness' house; solid residues were removed from the fluid and treated separately in a bucket of fresh acid to complete the dissolution (Vermeij et al. 2015).

The second victim was shot, undressed and subsequently put in a plastic barrel. This barrel was transported to the cellar of the witness' house. Successively, the barrel was filled up with a mixture of concentrated hydrochloric and sulfuric acid. The mixture was stirred regularly, and floating fatty residue was skimmed off the top and drained in a sink. Solid substances were removed from the barrel and were set apart and treated separately in smaller barrels of fresh acid. After three weeks, when the body was fully dissolved, the remaining fluid was poured down the same drain nearby the witnesses' house (Vermeij et al. 2015).

To substantiate the witness' initial statement, several samples were taken from the floors of the garages and the soil that was underneath the floor of the first garage; several cores were also drilled from the concrete floor and from the tiled floor in the witness' house cellar. The witness gave conflicting statements on the types of acids that were used to dispose of the bodies, so the drilling cores and the soil samples were extracted in deionized water to find out which acids were exactly used. After sifting through the contents of the drain, one pivot tooth, a small piece of epidermis and several particles with the appearance of bone were found; a pivot tooth is a dental implant that secures an artificial crown to the root of the tooth by a typically metallic pin. However, all the bone-like particles turned out to be stone-like materials. After sifting through the contents of the drain again, this time using an ultraviolet light source, several auto-fluorescent particles were secured, four of them with the same elemental composition as bone. The remnants were subjected to DNA analysis, but it was not possible to obtain a DNA profile from the victims. The soil samples yielded concentrations of chloride, sulfate, nitrate and phosphate, which may be an indication that a mixture of hydrochloric, sulfuric and nitric acid was used to dissolve the bodies, as the phosphate would come from the bones themselves. The

same conclusion can be drawn from the results from the drilling cores; however, there are other well-known sources of chloride, sulfate and nitrate (Vermeij et al. 2015).

If time and the available amount of acid are not limiting factors, it is theoretically possible to dissolve a human body in acid completely, without leaving any macroscopic detectable residues. However, gallstones and artificial components, such as artificial teeth and implants, are resistant to acid and will at least partly survive the dissolution. However, even if the body does not contain one of those components, it is most likely that at least some microscopic residues of bone can be found, ultimately leading to a positive identification (Vermeij et al. 2015).

"Detergent Suicides"

In another case report, accounted by Pokines and Springer (2016), skeletal remains were identified as an adult male who had gone missing approximately six years previously, and no trace of the individual was found at the time of disappearance. When the discovery of an isolated skeletal element on a dirt road where scavenging animals had likely dispersed the bone prompted a renewed search of the area, the rest of the remains were found a short distance away from the found element in an intact tent. Upon investigation, multiple bottles of The Works® Disinfectant Toilet Bowl Cleaner and Bonide® Lime Sulfur Spray, some of which were open, were recovered; the active ingredients of those products are hydrochloric acid and calcium polysulfide. When combined, the substances produce hydrogen sulfide gas, which is irritating to the eyes and respiratory system, and in high concentrations, causes pulmonary edema and death (Palmer, 2009). Fatal international exposures in the United States have not been described in the medical literature, however, suicides using hydrogen sulfide gas have been described in Japan

since 2007. Those suicides have been dubbed "detergent suicides" by the media because they are carried out by mixing household chemicals to produce toxic concentrations of gas (Pokines and Springer, 2016).

Localized areas of bone surface corrosion were present throughout the remains, and interestingly, the left tibial midshaft displayed an unusual band of localized corrosion that may be associated with clothing wicking corrosive fluid to this area, combined with compression of the remains onto this location. However, the portion of the skeleton most affected was the right foot area, including the distal half of the right fibula, with the distal fibula epiphyseal end completely corroded away, and most bones of the right foot also exhibiting corrosion. The areas of bone loss are consistent with contact of the corrosive solution pooling on the tent fabric underneath the remains. However, the localized corrosion of bone could be mistaken for a multitude of possibilities: coffin wear, various pathological conditions or perimortem trauma (Pokines and Springer, 2016).

The investigators overall concluded that the death was a suicide, and the authors note that suicides caused by mixing similar types of readily available household products to produce hydrogen sulfide gas are increasing, and the information about how to do so is freely available from multiple sources. Investigators, therefore, may increasingly encounter skeletal remains in proximity to corrosive products. That case shows that highly localized corrosion of bone can occur from various corrosive agents. The case analysis also benefitted from the clearly labeled chemical bottles that allowed the determination of the relevant chemical compounds present; where that is lacking, X-ray fluorescence analysis may detect the chemicals associated with a set of remains. The recovery of the remains and their complete contextual information along with a

thorough taphonomic examination as part of the biological profile also were necessary to understand the unique damage encountered in that case (Pokines and Springer, 2016).

Effects of Soil pH on Human Tissue and Bone

Outlined thus far are the various effects of household corrosive agents on tissue and bone, but, further consideration of the topic needs to acknowledge other factors that could affect the decomposition process. Of course, various taphonomic processes are accredited such as temperature, precipitation, scavenging of animals, etcetera. However, studying soil pH is crucial for this particular study, as acidic and alkaline levels should have a specific effect on the tissue and bones that are buried in those soils. Burial environments are a complex and dynamic system of interdependent chemical, physical and biological processes. Such processes influence, and are influenced by, the inclusion of a body and its subsequent decay (Haslam and Tibbett, 2009). Haslam and Tibbett (2009) carried out a study investigating three fresh soils of contrasting pH: a Podzol (acidic), a Cambisol (neutral) and a Rendzina (alkaline), in which skeletal muscle tissue of known mass was allowed to decompose.

Typically, acidic soils with a pH of 3.0–5.5 are dominated by fungal communities, whereas neutral soils with a pH of 5.5–7.5 provide ideal conditions for bacteria, and alkaline soils with a pH of 7.5–9 may be dominated by fungi again, especially in the conditions left by a cadaver post-putrefaction. The authors conducted a laboratory study using the above mentioned soils, which were sampled from the southern coast of England and chosen due to their geographical proximity. One hundred grams (dry weight) of each of the three soils was calibrated to sixty percent water holding capacity with distilled water inside sealable polyethylene bottles and incubated with and without skeletal muscle tissue samples for forty-two

days at 22°C. Weekly measurements were made from twelve randomly selected incubation containers, and twelve containers were also randomly selected to be harvested at forty-two days, and those containers also had carbon dioxide respiration monitored by the use of alkaline traps (Haslam and Tibbett, 2009).

Substantial skeletal muscle tissue mass was lost in all soils within the first seven days of the incubation period: 39% in the Cambisol, 62% in the Rendzina and 55% in the Podzol. After twenty-one days of incubation, the majority of tissue decomposition had occurred, and the remaining mass of skeletal muscle tissue was 10% in the Cambisol, 27% in the Rendzina and 8% in the Podzol; at the end of the six-week period there was little to no tissue left in any of the soils. A further test comparing the three soils showed that the mean values for skeletal tissue mass loss over the six-week incubation period were significantly different for each soil type. The authors concluded that the soil type had a considerable effect on the decomposition of the tissue buried in soil. They note that the differences in the rate of decomposition were over three times greater in the Podzol compared with the Rendzina after twenty-one days, "This result has major implications for forensic taphonomy as little consideration has been given to the type of soil that a buried cadaver (or part thereof) is found in, and this question must now be pursued with vigor" (Haslam and Tibbett, 2009: 902).

Insect Contact with Human Tissue

A final study conducted by Li, Wang and Wang (2016) compared the decomposition of a pig carcass in open air with that of one placed in a methyl methacrylate box to prevent insect contact. Though this study pertains mostly to insect contact with the tissue, they are also just comparing open air decomposition with contained air decomposition. Various factors effect

decomposition and as the authors state, “Carcass decomposition is a complex process influenced by many biotic and abiotic factors, including autolysis of individual cells by internal chemical breakdown, tissue autolysis from liberated enzymes, and further tissue breakdown from external processes introduced by intestinal/environmental bacteria and arthropods” (Li et al., 2016: 92).

Their study was conducted in 2006 in in the Panyu Forensic Autopsy Center of Guangzhou, South China. One pig was placed in a methyl methacrylate box (Pig A, PA) with the upper part of the left and right walls made of nylon mesh with a sliding cover on the top, while the other pig was placed in open air (Pig B, PB) and covered with wire mesh to prevent scavenging; both sites were in the shade to prevent exposure to direct sunlight. The carcasses were observed and photographed twice a day until the study concluded. The authors concluded that the decomposition process of the two carcasses were markedly different, the pig in the box decomposed slowly and the pig in open air decomposed quickly (Li et al., 2016).

Pig A had easily discernible stages, fresh stage, bloated stage and the deflated decay stage, and the durations were 0-1 day, 2-11 days and 12-26 days respectively. There was still a large amount of soft tissues remaining on Pig A on day 26. A series of postmortem morphological changes including livor mortis, rigor mortis and algor mortis were observed during the decomposition process. However, the carcass did not undergo any obvious change after the deflated decay stage, and the putrefactive liquids were significantly decreased. There was no insect activity on PA, however, adult flies laid large amounts of eggs through the nylon mesh, which were removed were cleared manually (Li et al., 2016).

Pig B underwent five identifiable stages of decomposition: fresh, bloated, active decay, post-decay and skeletonization. Those stages occurred 22.3 hours, 62.47 hours, 123.63 hours and 246.5 hours respectively, from the start of the experiment. There was no soft tissue present

and only bones remained on the carcass on day 26. The same postmortem morphological changes that occurred on Pig A were also observed in the early stages of decomposition of Pig B. Insect activity on PB obeyed the basic rule of entomology (Li et al., 2016).

Li et al. note that the main differences in the decomposition process of carcasses in enclosed and open-air conditions are mainly due to the presence or absence of insects. In the absence of insects, the decomposition was significantly delayed. However, many abiotic and biotic factors can affect the rate of decomposition and insect succession on remains, including geographic location, season, climatic conditions, habitat and experimental design. Also, the cause of death or the treatment of the body after death contributes significantly to decomposition rates (Li et al., 2016).

The present study aims to answer some of those beckoning questions about dissolving human bodies in corrosive chemicals as a means to dispose of a body after a murder has been committed. The previous body of literature has informed my hypotheses and expectations by explaining the potential effects sodium hydroxide has on various human body tissues, and also by noting the other factors affecting the decomposition process.

Chapter 3 – Hypotheses and Expectations

Hypotheses

Two hypotheses will be tested in this study:

1. The two pig legs in the tubs that have a pound and a half of lye either dissolved with water or as a powder sprinkled on top of the specimens will decompose faster than the two tubs with only half a pound of lye dissolved or sprinkled over the specimens.
2. The two pig legs that are submersed in their respective lye solutions will overall decompose faster than the buried specimens with powdered lye sprinkled on top.

Expectations

Sodium hydroxide is corrosive to all body tissues; concentrated vapors cause serious damage to the eyes and respiratory system. Ingestion of sodium hydroxide can cause severe necrosis, with stricture of the esophagus and death. Contact with the skin can result in dermatitis, loss of hair, and necrosis due to irritation; skin types vary in sensitivity to caustic irritation (Committee on Toxicology, 1984). Therefore, during this experiment, I expect that the specimens that are in contact with greater amounts of sodium hydroxide will decompose faster than the specimens that are in contact with lesser amounts of sodium hydroxide. Sodium hydroxide toxicity depends on the concentration of the solution and the duration of its contact with tissue. The chemical acts locally, exerting a strong corrosive action whose mechanism is not known, and causes almost immediate degeneration of the tissue, which can result in rapid absorption of the chemical into the circulatory system in living specimens.

Many toxicological evaluations of sodium hydroxide have been carried out in animals; the studies have focused on the eyes, skin and lungs as targets. Table 1 depicts those results

(Committee on Toxicology, 1984). There are no qualms that sodium hydroxide facilitates in disintegrating tissue, therefore, I expect all specimens to decompose faster than if there was no lye present.

Table 1: Test results of the effects of sodium hydroxide on rabbits and mice.

Species	Route	Dose	Duration of Exposure	Effects	Reference
Rat	Skin	50%	1 min, no wash 1 min, HA_c wash 1 min, H_2O wash	Edema, sloughing Edema, sloughing Edema, limited sloughing	Davidson, 1927
Mouse	Skin	50%	Immediate rinse 30 min, rinse 1 h, rinse 2 h, rinse No wash	No burn, no dead Burn, 1/5 dead Burn, 2/5 dead Burn, 4/5 dead Burn, 5/7 dead	Bromberg etal., 1965
Rat	Eye	40%	NG[a]	Necrosis, death	Cosgrove and Hubbard, 1928
Rabbit	Eye	20%	10 s	Necrosis	Hubbard, 1937; Hubbard, 1938
Rabbit	Eye	0.2%	3 min	Necrosis	Hughes, 1946
Rabbit	Eye	pH 11 pH 12	15 min 15 min	Slight injury Necrosis	Grant and Kern, 1955
Rabbit	Eye	2%	30 s	Necrosis	Brown, 1971; Brown and Weller, 1970; Brown etal., 1969[a,b,c]; 1970
Rabbit	Eye	0.5%[b] 2.0%[b] 8.0%[b]	Not specified Not specified Not specified	Intraocular pressure up Intraocular pressure up Intraocular pressure up	Chiang etal., 1971

Committee on Toxicology. Sodium Hydroxide. Emergency and Continuous Exposure Limits for Selected Airborne Contaminants: Volume 2. National Academy Press 1984; 87-94.

Since I am experimenting with two dissimilar deposition environments, I also expect that the pig legs that are submerged in their respective lye solutions will overall decompose faster than the buried samples. Insects will not be a factor during the majority of this experiment because the bulk of the trial is taking place during winter, so the buried samples will most likely freeze and perhaps begin to mummify. Because of this, it is reasonable to expect for the submersed specimens that will remain at a constant temperature will decompose faster than the buried specimens that will be exposed to variable temperatures.

Chapter 4 – Materials and Methods

Four dissimilar deposition environments were tested in this study: two lye solutions placed in a temperature-controlled setting and two soil environments left outside. One of each deposition environment was associated with a pound and a half of lye, while the other two different environments were associated with half a pound of lye. Large Rubbermaid® Roughneck Storage totes were used for this experiment due to their sturdiness, chemical resistance, and ability to withstand harsh temperatures. They are made with a durable polyethylene material that the lye cannot dissolve. Four one-pound containers of 100% lye crystals (pictured in Figure 4.1) were purchased from a local hardware store and used for this experiment. Lye is readily available to the public and is valued for its cleaning effects. Sodium hydroxide is commonly the major constituent in commercial and industrial oven cleaner and drain openers due to its grease-dissolving abilities. It is also used in soap making and to cure many types of food, such as olives, canned mandarin oranges and pretzels, to name a few. In the United States, food-grade lye must meet requirements outlined in the Food Chemicals Codex (FCC), as prescribed by the U.S. Food and Drug Administration (FDA).

Figure 4.1: Lye used in this study.

Each tote housed a single, fully-fleshed hind domestic pig (*Sus scrofa domesticus)* leg with the foot still attached; the specimens were obtained from Farm to Market Pork in Missoula, MT. Current considerations suggest that pig cadavers best mimic human decomposition because of their comparable skin structure, subcutaneous fat layer, fat-muscle ratio, body mass and

physiology (Schotsmans et al., 2014). Single pig legs were used for this experiment because of the time constraints decomposing a full corpse would entail.

Table 2: Experiment information.

Tote/Pig	Amount of Lye (lbs.)	Concentration	Solution/Burial	Indoor/Outdoor
A	0.5	1.2%	Solution	Indoor
B	0.5		Burial	Outdoor
C	1.5	3.6%	Solution	Indoor
D	1.5		Burial	Outdoor

Indoor Specimens

Both of the specimens that were in the temperature-controlled environment were prepared by filling each tote with 5 gallons of cold water. Since the totes will be covered for the duration of the study, five 1/4" holes were drilled in the lid to allow for air circulation. Lye was carefully measured out to comparative amounts of 0.5 pound (Tote A) and 1.5 pounds (Tote C), the lye was then added slowly to the cold water in each tote and subsequently stirred to ensure all the lye dissolved. It was calculated that Tote A had a sodium hydroxide concentration of 1.2%, while Tote C had a concentration of 3.6%. An increase in water temperature was immediately apparent with Tote C; it then cooled to ambient temperature. A floating thermometer was placed in Tote A to ensure a constant temperature of 40°F to 50°F. Once the solutions were made, Pig A (Figure 4.2) and Pig C (Figure 4.3) were placed in their respective totes (pictured in Figures 4.4 and 4.5), photographed, and remained undisturbed, except for specialty photographs, for the remainder of the experiment.

Figure 4.2: Pig A before submersion.

Figure 4.3: Pig C before submersion.

Figure 4.4: Tote A on Day 1.

Figure 4.5: Tote C on Day 1.

Outdoor Specimens

Both of the specimens that were left outside were prepared by filling each tote three-quarters full with Miracle-Gro Moisture Control® potting mix; potting mix was used for this experiment due to the time of year the study took place. The outdoor totes were also covered for the duration of the experiment, therefore, twelve 5/16" holes were drilled in the lid to allow for air circulation and potential insect activity when the weather got warmer. Pig B and Pig D were placed in their respective totes (pictured in Figures 4.6 and 4.7), and lye was carefully measured out to relative amounts of 0.5 pound (Tote B) and 1.5 pounds (Tote D) and then subsequently sprinkled on top of each pig leg (pictured in Figures 4.8 and 4.9). The specimens were then covered with a thin layer of the potting mix, photographed, and remained undisturbed for the remainder of the experiment. However, in order to take photographs of the progress, some potting mix had to be brushed off the specimens. Because of this disturbance, the portion of the pig legs that were uncovered during photographs were consequently left unearthed from the potting mix.

The specimens were photographed and analyzed every 48 hours; the temperature and time of day were recorded, as was the condition of the specimens (notes are included in Appendix A). The samples were examined every 48 hours due to the amount of time unaltered decomposition takes to complete, however, the time of day the inspections took place was not consistent. This experiment continued to be active until no further consistent change is recorded with the specimens after 96 hours (4 days).

Once the samples were removed from their respective totes, they were photographed and each were subjected to a specific test based on the environment they were exposed to. A bone consistency test was conducted on the indoor specimens (Pig A and Pig C), in which the exposed

bone was probed by a stainless steel rod to determine the consistency and hardness of the bone. This test was used to ascertain whether the sodium hydroxide had a similar effect on the bone as it did on the skin, muscle and nails. A tissue texture test was conducted on the outdoor specimens (Pig B and Pig D), in which the tissue was dissected to determine the dryness of the flesh.

Figure 4.6: Pig B before lye placement.

Figure 4.7: Pig D before lye placement.

Figure 4.8: Pig B after lye placement.

Figure 4.9: Pig D after lye placement.

Chapter 5 – Results

Indoor Specimens

Pig A overall showed little signs of decomposition throughout the experiment. Unlike Tote C, Tote A did not have an immediate increase in temperature when the lye was poured into the cold water, nor were there any bubbles from agitating the mixture. When Pig A was examined before being placed in its tote, there were no breaks in the skin, the toenails were bright pink in color, some veins were noticeable towards the cut mark, hair was present near the toes, the skin was light pink in color, and the exposed muscle was a rich pink color. The lye solution that the pig leg was placed in was clear, and no residue was present as the lye dissolved entirely (pictured in Figure 4.4).

Detailed notes on Pig A are attached in Appendix A, but various focal points are as follows: on Day 5, exposed muscle had begun to change in appearance, exhibiting a "bubbly" texture; on Day 7, the first break in the skin is visible to allow for bloat; on Day 9, the water color had started to substantially darken in color; on Day 13 (figure 5.1), a reflective floating film is noticeable; on Day 33 (figure 5.2), solidified fat was present on underside of sample near exposed muscle; on Day 45 (figure 5.3), Pig A's skin had started to turn yellow in color; on Day 47 (figure 5.4), there was noticeable marbling, and hair was still present around the toes. By the end of the experiment, Pig A had been submersed in its tote for 60 days. The specimen did not go through the typical stages of decomposition as expected, instead it was still completely recognizable as a pig leg.

On Day 60 (figure 5.5), the lye solution that housed Pig A had changed from a clear solution to a semitransparent brown color and there was a reflective, floating film that covered

the majority of the solution. The temperature of the solution had remained between 40°F and 50°F during the study. The skin color of the leg had turned bright white, as did the toenails, and the veins that were near the cut mark were still noticeable. However, there appeared to be signs of livor mortis on the side that the pig leg was resting on. There were three distinguishable breaks in the skin, all three were near the toes, the largest one was superior and two smaller ones were inferior. The exposed muscle now appeared bleached in color, though the texture of the muscle did not change; solidified fat was also observable around the muscle tissue. The typical stages of decomposition were not discernable with Pig A, however, significant alterations occurred with the solution color, as well as relevant changes to the specimen itself, indicating some sort of reaction to the 0.5 pound of lye mixed in with the water.

Figure 5.1: Pig A on Day 13.

Figure 5.2: Close-up of Pig A showing solidified fat.

Figure 5.3: Pig A on Day 45.

Figure 5.4: Close-up of Pig A showing marbling.

Figure 5.5: Pig A on Day 60.

Unlike Pig A, Pig C underwent substantial changes during the 60 days it was submersed in a solution with 1.5 pounds of lye. Pig C had very similar characteristics to Pig A on Day 1 before being placed in its tote. Pig C was a little larger in overall size than Pig A, but was also light pink in color and the exposed muscle was a rich pink color. The toenails were also pink in color, and there was some callusing on the inferior portion of the foot, which Pig A did not have. There were no breaks in the skin and some large veins were visible on the specimen's skin. The lye solution that Pig C was placed in was clear, though there was bubbling when the lye was stirred into the water (pictured in Figure 4.5).

Detailed notes on Pig C are also attached in Appendix A, but various highlights are as follows: on Day 3 (Figure 5.6) there was a noticeable odor upon taking off the lid, the water had turned murky and the leg was extremely bloated; on Day 7 (Figure 5.7) there was a break in skin to allow for bloat; on Day 11 (Figure 5.8) there was an apparent residue near the exposed muscle; on Day 21 (Figure 5.9) there was exposed phalanges and the toenails had disintegrated completely; on Day 45 (Figure 5.10), a large break in the skin was obvious and unidentifiable parts of the toe area had sunk to the bottom; on Day 47 (Figure 5.11), the foot was completely unrecognizable, it had an extremely jelly consistency and the bones were very soft.

On Day 60 (Figure 5.12), the once-clear lye solution that housed Pig C had changed to a dark brown color. The temperature of the solution had remained between 40°F and 50°F during the study, although there was an increase in temperature on Day 1, it then cooled to ambient temperature. The solution was dark brown in color, and was slightly opaque from the tissue that had sloughed off the leg and was subsequently floating or resting at the bottom of the tote. The foot had completely decomposed, and only the large part of the leg was left. The tissue and bones were extremely malleable, and there was hemorrhaging on the proximal ends of the tibia

and fibula. The exposed muscle had disintegrated completely and only solidified fat was left. It was difficult to discern what tarsals and metatarsals were left, if any. Typical early stages of decomposition for Pig C were distinguished throughout the experiment, indicating a significant reaction to the 1.5 pounds of lye.

Figure 5.6: Pig C on Day 3.

Figure 5.7: Close-up of Pig C on Day 7 showing break in skin.

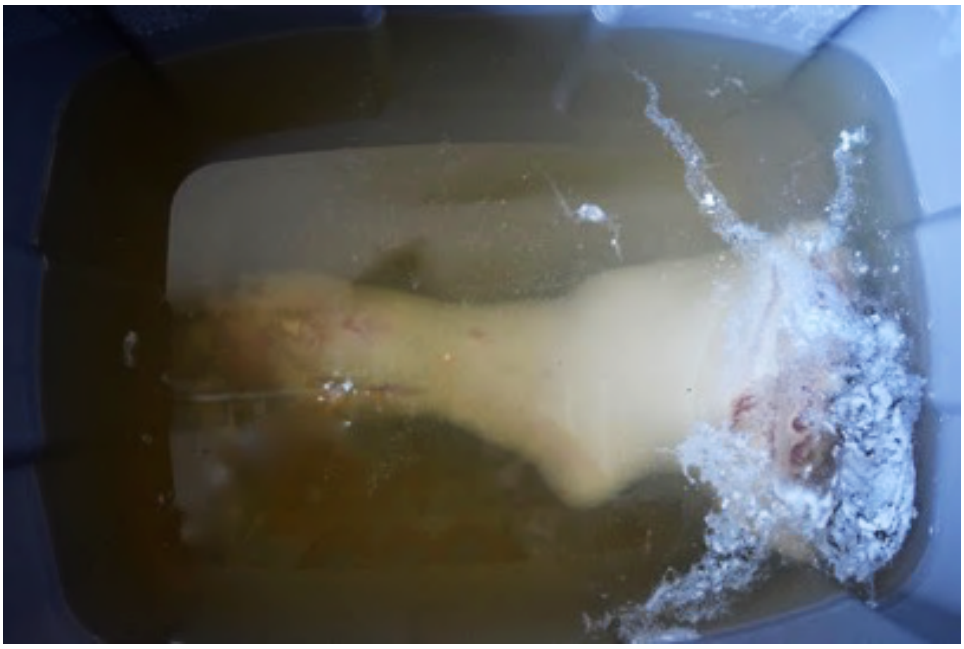

Figure 5.8: Pig C on Day 11.

Figure 5.9: Pig C on Day 21.

Figure 5.10: Pig C on Day 45.

Figure 5.11: Close-up of Pig C showing foot decomposition.

Figure 5.12: Pig C on Day 60.

Bone Consistency Test

A bone consistency test was performed to determine the integrity of the exposed bone on Pig A and Pig C after they had been exposed to the sodium hydroxide for 60 days. When the exposed bone of Pig A was probed by a stainless steel rod, the bone was hard and no marks were left on it; there was exposed cartilage that was easily indented, but the bone was structurally intact. However, when the exposed bone of Pig C was probed by the same rod, it was extremely soft and impressionable, the dowel could have easily been interpolated through the bone.

Once I located miscellaneous metatarsals and tarsals that had settled to the bottom of the tote by the end of the experiment, I was able to compress the bones entirely. However, when the tibia and fibula were separated from the remaining tissue and subsequently probed, they still remained hard and impenetrable.

Outdoor Specimens

Like the indoor specimens, both of the outdoor specimens had the same characteristics before they were placed in their respective totes: the skin was light pink in color, the toenails were a darker pink, the exposed muscle was a rich pink color, and hair and veins were also visible; there were no breaks in the skin. Overall, Pig B and Pig D showed little decomposition throughout the 60 days they were buried in their respective totes. The outside temperature ranged between 25°F and 54°F during the experiment when the specimens were examined, but was partially consistent on the days the samples were examined, most likely due to the time of day. The most notable changes with Pig B and Pig D occurred between Day 5 and Day 11.

Detailed notes are attached in Appendix A, but various climaxes are as follows: on Day 5 (Figures 5.13 and 5.14), Pig D showed the slightest beginning stages of decomposition with some skin sloughing near the foot; on Day 7 (Figures 5.15 and 5.16), both pigs looked as though they were going to mummify, the skin on both samples had turned brown and is starting to feel leathery; on Day 11, Pig D had a slight odor upon taking off the lid, it had softer skin than Pig B, both legs were still stained. After Day 11, there was little change with both specimens – they remained stained in color and the skin had a consistent texture. On Day 60 (Figures 5.17 and 5.18), there was no further change with Pig B and Pig D, but they had both shrunk in size, probably due to dryness, however, the exposed muscle was still soft to the touch. Once the samples were removed from their totes, medial and lateral photos were taken to show the difference between the side of the legs that were in contact with the lye and the side of the legs that were not exposed to the air or lye. Those photographs are pictured in Figures 5.19, 5.20, 5.21 and 5.22.

Figure 5.13: Pig B on Day 5.

Figure 5.14: Pig D on Day 5.

Figure 5.15: Foot of Pig B on Day 11.

Figure 5.16: Foot of Pig D on Day 11 showing skin sloughing.

Figure 5.17: Pig B on Day 60.

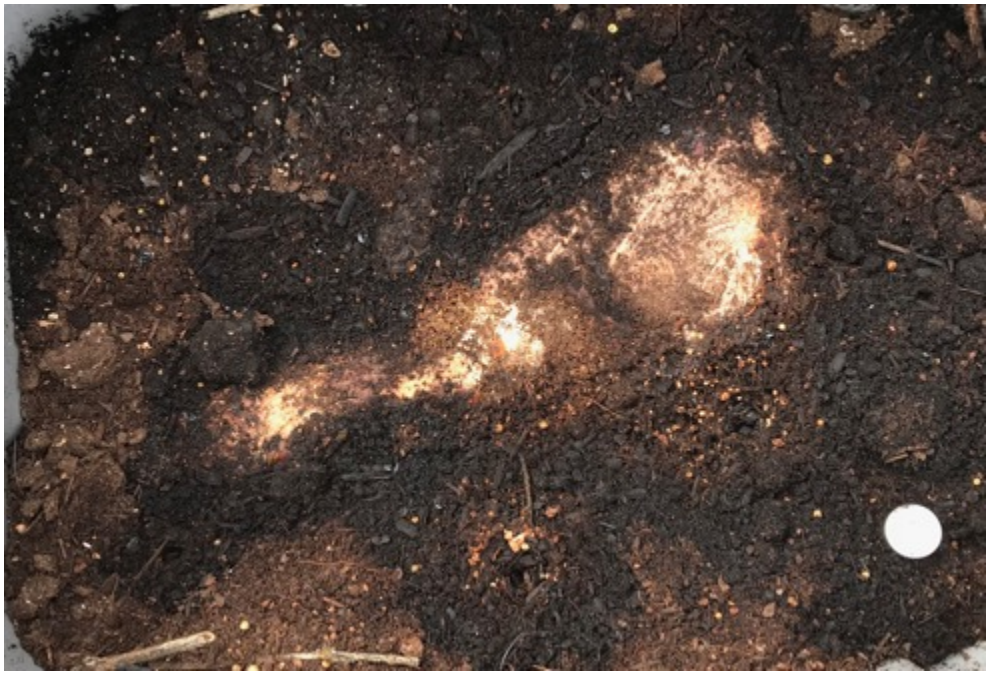

Figure 5.18: Pig D on Day 60.

Figure 5.19: Pig B on Day 60, side exposed to lye.

Figure 5.20: Pig B on Day 60, side not exposed to lye.

Figure 5.21: Pig D on Day 60, side exposed to lye.

Figure 5.22: Pig D on Day 60, side not exposed to lye.

Tissue Texture Test

When Pig B and Pig D were unburied and removed from their totes, they were subjected to a tissue texture test to examine the consistency and texture of the exposed tissue. The tissue was palpated in various places to determine if the skin had different textures from the experiment. The majority of the skin textures of both specimens were very similar: leathery to the touch, but still soft and impressionable. However, the skin near the feet of each specimen was much drier, perhaps because its much thinner than on the rest of the leg. The exposed muscle on each specimen was extremely pulpous, as if it had begun the first stages of decomposition.

Bone Analysis

Various bones of Pig C were separated from the remaining tissue in order to analyze the effects the sodium hydroxide had on them. Only Pig C's bones were examined because they were easily detached from the remaining tissue and the effects of the sodium hydroxide were obvious. Pig C was removed from its tote, assorted bones were disarticulated by hand and subsequently cleaned with a Dawn® dish soap solution (two parts water to one part soap) to remove the residual tissue. Once the bones were cleaned, they were left to dry out for 5 days before examination. Numerus bones were collected, but the tibia, fibula, calcaneus, astragalus and 4th metatarsal were eventually chosen for consideration due to their dissimilar appearances from one another and the noticeable results on the bones from the lye.

Tibia and Fibula

The tibia and fibula diaphyses of Pig C were not exposed to the sodium hydroxide for the majority of the experiment, but the epiphyses were unprotected due to the butcher cut. Nonetheless, the integrity of the tibia and fibula were altered. The tibial epiphyses were disarticulated so the proximal and distal metaphyses are present. The diaphysis remained white in color, while the proximal metaphysis is brown in color with some blood staining and the distal metaphysis is tan in color. There is obvious flaking on the tibial tuberosity (pictured in Figure 5.23) and slight flaking on the distal metaphysis. There is noticeable cracking on the lateral side of the diaphysis (pictured in Figure 5.24), and slight cracking on the medial side. The integrity of the cortical bone has been compromised below the tibial plateau (pictured in Figure 5.25) and very faintly on the distal end; it is highly porous on the proximal end. However, it is difficult to discern whether this was caused by the sodium hydroxide or due to stresses during life.

The fibula has slight flaking on all sides of the proximal and distal ends. There is very discernable flaking on the medial side of the proximal end (pictured in Figure 5.26), and looks as though the cortical bone is separating from the trabecular bone. There is cracking along the medial edge of the fibula that spans more than half the diaphysis. The integrity of the cortical bone on the proximal end has also been compromised (pictured in Figure 5.27), almost as if the cortical bone has disintegrated and there is only trabecular bone present.

Figure 5.23: Close-up of tibia of Pig C showing flaking. (Anterior View)

Figure 5.24: Tibia of Pig C showing cracking. (Medial View)

Figure 5.25: Close-up of tibia of Pig C showing porosity. (Posterior View)

Figure 5.26: Close-up of fibula of Pig C showing flaking. (Medial View)

Figure 5.27: Close-up of fibula of Pig C showing integrity of cortical bone. (Anterior View)

Calcaneus, Astragalus and 4th Metatarsal

A majority of the tarsals and metatarsals were indiscernible by Day 60, so the calcaneus, astragalus and 4th metatarsal were chosen for this analysis due to their identifiability and effects of the sodium hydroxide on the bone. The calcaneus was altered substantially during the study. There is substantial cracking along the entire posterior side (pictured in Figure 5.28), on the sustentaculum tali and along the articular surfaces. There is micro- and macroporosity on all surfaces of the calcaneus, but it is most prominent near the cracking on the lateroposterior side. Regions of the cortical bone appear to have been entirely disintegrated, and what remains is smooth, yellow-colored trabecular bone that has been altered by the lye (pictured in Figure 5.29). When the calcaneus was removed from the tissue, it was extremely malleable. There is also discoloration near the cracking on the dorsal side. Since the calcaneus dried out, it has hardened, but remains the bone texture remains chalky.

The astragalus was also altered considerably during the study. There is significant cracking on both lateral (pictured in Figure 5.30) and medial sides of the trochlea, as well as down the midline. There is extreme disintegration of the cortical bone on the inferior and lateral sides of the astragalus, so the trabecular bone has transformed into the same smooth, discolored material that was observed on the calcaneus (pictured in Figure 5.31). There is macroporosity along the nonarticular surfaces and microporosity throughout the entire bone. There is slight discoloration on the anterior and posterior portions of the trochlea, and also along the inferior articular surface.

The 4th metatarsal experienced the most change out of the bones analyzed from the sodium hydroxide during the experiment, most likely due to the extreme decomposition of the foot. There is substantial cracking on the medial and lateral (pictured in Figure 5.32) sides of the

diaphysis and also on the distal metaphysis. There is microporosity throughout the entire bone, but it is extreme on the plantar side near the metaphysis and on the medial and lateral sides of the proximal half of the diaphysis. The most extreme alterations occurred on the dorsal side, where the cortical bone has almost entirely disintegrated (pictured in Figure 5.33). Modified trabecular bone remains that is soft and easily manipulated; I was able to scrape layers off the bone with my fingernail. There was also some discoloration of the trabecular bone near the distal epiphysis. The sodium hydroxide had various effects on the identifiable bones of Pig C, but the most notable changes were the disintegration of the cortical bone, the change in appearance and texture of the trabecular bone, and the considerable cracking and flaking on all the bones.

Figure 5.28: Calcaneus of Pig C showing cracking. (Posterior View)

Figure 5.29: Calcaneus of Pig C showing modified trabecular bone. (Medioposterior View)

Figure 5.30: Astragalus of Pig C showing cracking.
(Lateral View)

Figure 5.31: Astragalus of Pig C showing modified trabecular bone.
(Anterior View)

Figure 5.32: 4th metatarsal of Pig C showing cracking.
(Lateral View)

Figure 5.33: 4th metatarsal of Pig C showing lack of cortical bone and modified trabecular bone.
(Dorsal View)

Chapter 6 – Discussion

The purpose of this study was to examine the various effects that sodium hydroxide, commonly known as lye, has on the decomposition process in differential deposition environments. Two hypotheses were proposed for this experiment. The first was that the two pig legs (Pig C and Pig D) in the tubs that have a pound and a half of lye either dissolved with water or as a powder sprinkled on top of the specimens will decompose faster than the two legs (Pig A and Pig B) in the tubs with only half a pound of lye dissolved or sprinkled over the specimens. The second hypothesis was that the two pig legs that are submersed in their respective lye solutions will overall decompose faster than the buried specimens with powdered lye sprinkled on top.

Based on previous literature, it is accepted that specimens that are in contact with greater amounts of sodium hydroxide will decompose faster than specimens that are in contact with less amounts of sodium hydroxide. This was found to be partially true throughout the course of this study. Pig C underwent the most decomposition during this study because it was exposed to 1.5 pounds of lye and it was submersed in a temperature-controlled environment. Pig C exhibited some typical decomposition stages (Table 3), apart from the fresh stage, but it reached the bloat stage by Day 5. After the bloat stage, however, Pig C was incapable of going through the active decay and advanced decay stages due to the absence of insect activity and because it was submersed in a solution. Though active decay and advanced decay were not observed, the tissue and nails continued to decompose by dissolution.

Table 3: Decomposition Staging Scale.

Category	Stage	Changes
Putrid	I	Early putrid odor Tissues tacky Lividity fixed
	II	Hemolysis Early skin slippage Intense livor
	III	Prominent hemolysis Tissues soft and slick Skin slips easily
Bloating	IV	Early body swelling Marbling Bullae Discoloration
	V	Moderate swelling
	VI	Maximal body swelling
Destruction	VII	Release of gases Exhausted putrefied soft tissues Total destruction of blood
	VIII	Partially skeletonized Adipocere Mummification
Skeleton	IX	Skeleton with ligaments
	X	Skeleton with no soft tissues

Haglund WD, Sorg MH, editors. Forensic Taphonomy: The Postmortem Fate of Human Remains. Florida: CRC Press, 1997.

Whereas Pig B, which was also exposed to 1.5 pounds of lye, did not show any signs of average decomposition; this is likely due to the cold temperatures it was exposed to. Winter in Montana is highly unpredictable, but outside temperatures ranged between 10°F and 55°F throughout the course of this experiment, which can lead to differential decomposition processes. Any soft tissue that has not been artificially or naturally preserved is subject to the postmortem processes of putrefaction and decay. Whereas desiccation occurs under conditions of dryness, putrefaction takes place in the presence of moisture and moderate temperatures. No putrefaction

occurs at temperature less than 39°F. Temperature has a direct effect on bacterial growth in both extremes of heat and cold, and in middle ranges. Freezing stops bacterial growth and preserves tissue by influencing cell division time, while boiling kills bacteria but destroys soft tissue. At temperatures below 55°F, bacterial reproduction is greatly impeded. At temperature between 32°F and 41°F, bacterial multiplication stops entirely and the time required for a single bacterial cell division to occur approaches infinity (Haglund and Sorg, 1997). Bacterial growth and insect activity were very minimal during the experiment, due to the cold temperatures Pig B was exposed to, therefore, it did not decompose at all.

Overall, the indoor specimens experienced more change during the experiment than the buried specimens. This was expected because, as noted above, Pig B did not decompose during this experiment, and neither did Pig D. Though Pig D was in contact with a greater amount of lye than Pig B, it did not decay due to the multiple factors effecting the decomposition process: temperature, moisture, insect activity, bacterial growth. Nonetheless, both Pig A and Pig C experienced overall much more collective change throughout the 60 days they were submersed. The temperature-controlled environment remained between 40°F and 50°F, which allowed for some bacterial reproduction and putrefaction. Though Pig A did not display as much decay as Pig C, the environment in which it was placed endorsed some significant changes. Water in which bodies are partially or totally submerged may accelerate or delay decomposition, depending upon whether it is salty or fresh, moving or still, or varying in pH. Water also has several physical and chemical effects on the decomposing chemical system. Because of its high specific heat, water has a stabilizing effect on temperature. Chemically, water acts as a buffer moderating the effects of tissue and environmental acidity and alkalinity, and ultimately serves

as a source of hydrogen for all cells (Gill-King, 1997). Since the submersed specimens were also exposed to sodium hydroxide, various other chemical reactions inevitably occurred.

Contrary to previous research (Hartnett et al., 2011; Cope and Dupras, 2009) that concluded that lye does not have much of an effect on tissue and bone, this study demonstrated that various reactions can occur due to exposure to sodium hydroxide. Hartnett et al. (2011) experienced dissimilar results in their study: when subjected to the lye, hair turned yellow and then brown and dissolved in 3 minutes; the fingernails remained structurally intact, but turned a fluorescent yellow color; the lye appeared to dissolve the fat in the flesh sample, but did not affect the other portions; the teeth remained unchanged (Hartnett et al., 2011). Their results are adversative to the present results of this study. The lye did not affect the integrity of the hair on the pig legs, hair remained intact on Pigs A, B and D throughout the study. The fingernails of Pigs A, B and D also remained structurally intact, but the nails of Pig A had turned white while the nails of Pigs B and D were soil-stained. The authors also noted that the lye dissolved the contents of the marrow cavity in their femur sample but did not alter the structure or color of the bone. Based on the bone analysis performed on the tibia, fibula, calcaneus, astragalus, and 4th metatarsal from Pig C, the lye did in fact alter the structure of the bone. Most notably, the integrity of the cortical bone was altered on all the bones examined, which subsequently resulted in transformation of the trabecular bone. There was also severe cracking and flaking on the bones, as well as micro- and macroporosity.

Cope and Dupras (2009) observed similar results to Hartnett et al. when they exposed teeth to sodium hydroxide. They state that sodium hydroxide proved to be the least effective in degrading the teeth, but significant changes were observed on the surface. Initial cracks in some of the teeth expanded with continual exposure to lye, while calculus on an incisor was

completely eliminated within 1 hour of the experiment. The enamel was slightly affected by the chemical, first with the appearance of a sheen affect and afterwards with minor enamel flaking; no other changes were evident. Though the anatomy of teeth is extremely different to the anatomy of skin, tissue and bone, Cope and Dupras witnessed little change with the teeth that were exposed to sodium hydroxide, which is quite contrary to what was observed with the submersed specimens in this study.

This study does have its limitations. First, the specimens were all domestic pig legs instead of human cadavers. Though there are positive similarities between pig and human tissues, they are not identical. If human cadavers could have been used for this experiment, then forensic methods would have been established to determine the effect of the corrosive chemical on the specimens. Estimating weight is an important forensic method used, though it's not always accurate, and is used to aid in positive identifications. Weight was not a factor in this study, therefore, future studies should take weight into consideration when testing effects of corrosive chemicals on various human or nonhuman tissues.

Another weakness of this study is that it took place between January and March in Montana, which is undeniably the coldest time of the year. As explained throughout this study, temperature is the most significant factor during the decomposition process and can enhance or hinder the development (Gill-King, 1997). All bodies move through essentially the same stages of decomposition, but temperature is the most important variable influencing the "dwell-time" in a particular stage and the overall velocity of the process (Gill-King, 1997). When conditions are ideal for decomposition, the temperature remains relatively constant. The variables affecting the decay rate of the human body cannot be isolated or controlled in experimental field studies because they are so interrelated (Mazza et al., 2005). Though two of the four specimens were

placed in a temperature-controlled environment, further experiments should ensure that temperature is considered when testing for specific results.

Chapter 7 – Conclusion

It is critical to understand the effects corrosive chemicals have on human body skin, tissue, hair, bones and teeth because perpetrators may use certain chemicals to enhance the decomposition process of their victims. Various chemicals have been tested, such as hydrochloric acid, sulfuric acid, phosphoric acid, bleach, and in the case of this present study, sodium hydroxide. Sodium hydroxide is a commonly used household product and is extremely obtainable by the public. However, sodium hydroxide has very destructive properties and theoretically, can be used to dissolve a body entirely.

Lye was chosen for this experiment because of its availability and contradictory previous research that it may or may not do damage to various tissues, depending on certain circumstances. The qualitative data generated by this study are extremely useful when a forensic case shows some evidence of chemical modification. Future experiments should include more extensive testing using complete body segments, perhaps an entire human body, while also testing other human tissues such as blood, semen and skin with the agent used in this study, and testing whether any elements of human DNA or other markers are detectable in the material remaining after dissolution. More modifications of the experiment context may also reveal variations in how chemical substances affect tissue, skin, hair and bone. Furthermore, other readily available agents should be tested for their effect on human tissue. Despite contradictory experiments on household chemicals, this study presented useful information for future forensic contexts in hopes that one day perpetrators will stop trying to dissolve remains in corrosive chemicals. We're onto you!

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Appendix

Appendix A – Notes taken during experiment

January 25, 2018 Day 1

- Experiment commences, totes are labeled and specimens are placed in their respective totes for the duration of the study.
- 38°F outside temperature.
- 2:00 P.M.

January 27, 2018 Day 3

- Pig A had some decomposition of exposed muscle.
- Pig C had visual decomposition of fat and exposed muscle from butcher cut, and was also starting to smell of decomposition.
- No visual change with Pigs B and D (buried specimens).
- 32°F outside temperature.
- 12:30 P.M.

January 29, 2018 Day 5

- Pig A didn't exhibit much change, exposed muscle still had a strange "bubbly" appearance, no odor.
- Tote C had noticeable odor upon taking off the lid, water color had changed from clear to a very murky greenish-brown. No more obvious decomposition, however, pig leg was very bloated.
- Pigs B and D didn't have much change, perhaps the very slightest beginning stages of decomposition with Pig D (there was minor skin sloughing near the foot).
- 36°F outside temperature.
- 11:45 A.M.

January 31, 2018 Day 7

- Pig A had a break in the skin to allow for bloat, but was not as bloated as Pig C, not very odorous.
- Pig C was very malodorous, very bloated, also had a break in skin from the pressure of bloating, water color was still murky.
- Pigs B and D looked as though there are going to mummify, the skin on both samples has turned brown and is starting to feel leathery.
- 34°F outside temperature.
- 1:00 P.M.

February 2, 2018 Day 9

- Pig A did not have much change, water had turned more murky than it was, but not by much.
- Pig C had much more decomposition and was especially obvious near the toes, extremely smelly.
- Pigs B and D were still stained, but not much more change.
- 38°F outside temperature.
- 2:00 P.M.

February 4, 2018 Day 11

- Pig A didn't have much change, water was still the same color, not anymore noticeable bloating.
- Pig C had definite decomposition, perhaps the skin was sloughing off near the toes, it was extremely bloated and odorous.
- Pig D had a slight odor and showed more signs of decomposition than Pig B. It had softer skin and an odor while Pig B did not. Both legs were still stained in color.
- 40°F outside temperature.
- 4:00 P.M.

February 6, 2018 Day 13

- Pig A showed little change, however, there was a reflective film floating on top of the water (fat maybe?).
- Pig C continued to show extreme decomposition around the toes, no other change.
- Little change with Pigs B and D, skin still stained in color.
- 47°F outside temperature.
- 5:00 P.M.

February 8, 2018 Day 15

- Pig A showed little change, break in skin has not increased in size, reflective film still present.
- The toes of Pig C are almost completely unrecognizable, very malodorous, white residue floating near exposed muscle (perhaps fat?), toenails almost completely dissolved.
- Little change with Pigs B and D, skin still stained in color.
- 54°F outside temperature.
- 1:30 P.M.

February 10, 2018 Day 17

- No change with Pig A.
- Much more decomposition on the toes of Pig C, extremely smelly.
- No change with Pigs B and D.
- 32°F outside temperature.
- 1:00 P.M.

February 12, 2018 Day 19

- Tote A water becoming more murky in color, film still present.
- Pig C still had strange white residue on exposed muscle that was noted on Day 15, toes still decomposing the fastest.
- No change with Pigs B and D.
- 33°F outside temperature.
- 12:30 P.M.

February 14, 2018 Day 21

- Tote A water was very murky, about the same color as Tote C water. Perhaps beginning signs of decomposition around toes. No more noticeable change.
- Pig C had phalanges exposed, toenails were disintegrated and toes were unrecognizable, extremely smelly, lots of floating fat near exposed muscle, water was dark brown in color, more skin breakage.
- No change with Pigs B and D.
- 36°F outside temperature.
- 2:30 P.M.

February 16, 2018 Day 23

- No change with Pig A.
- Pig C had more obvious phalanges present.
- No change with Pigs B and D.
- 34°F outside temperature.
- 4:30 P.M.

February 18, 2018 Day 25

- No change with Pig A.
- More phalanges present on Pig C, toenails completely dissolved.
- No change with Pigs B and D.
- 35°F outside temperature.
- 1:00 P.M.

February 20, 2018 Day 27

- No change with Pig A, exposed muscle still showed slight signs of decomposition.
- Toes disintegrated on Pig C, smell of decomposition very strong, starting to get difficult to see changes because of color of water.
- No change with Pigs B and D.
- 30°F outside temperature.
- 11:30 A.M.

February 22, 2018 Day 29

- No change with Pig A.
- Pig C foot is almost completely decomposed, many breaks in the skin.
- No change with Pigs B and D.
- 32°F outside temperature.
- 5:00 P.M.

February 24, 2018 Day 31

- No noticeable change with Pig A, slight odor, no more breaks in skin.
- No more noticeable change with Pig C.
- No change with Pigs B and D.
- 25°F outside temperature.
- 12:00 P.M.

February 26, 2018 Day 33

- I flipped Pig A to look at the bottom of the leg, the fat on the exposed muscle had solidified and looked like gel.
- Pig C had an extremely jelly-like consistency, even the exposed bones were soft (probed with a small hand axe).
- No change with Pigs B and D.
- 34°F outside temperature.
- 11:00 A.M.

February 28, 2018 Day 35

- No change with Pig A.
- No change with Pig C.
- No change with Pigs B and D.
- 38°F outside temperature.
- 4:00 P.M.

March 2, 2018 Day 37

- Pig A's "ankle" was very bloated, it still had a skin-like texture when probed, no more obvious change.
- Pig C showed more signs of decomposition near the toes.
- No change with Pigs B and D.
- 41°F outside temperature.
- 2:00 P.M.

March 4, 2018 Day 39

- Exposed muscle on Pig A has turned white in color, break on bottom of foot might have gotten a little bigger, perhaps more fat floating on top.
- Lots of white residue near exposed muscle on Pig C, distal phalange on first toe detached from intermediate.
- No change with Pigs B and D.
- 39°F outside temperature.
- 2:30 P.M.

March 6, 2018 Day 41

- No change with Pig A.
- The white residue that was near the exposed muscle on Pig C is a film that can be moved around/picked up and remains a single piece (probably fat).
- No change with Pigs B and D.
- 41°F outside temperature.
- 11:00 A.M.

March 8, 2018 Day 43

- No change with Pig A.
- No change with Pig C.
- No change with Pigs B and D.
- 48°F outside temperature.
- 1:00 P.M.

March 10, 2018 Day 45

- Pig A's skin has started turning a yellowish color, large slit in skin on bottom of foot, ankle very enlarged.
- Pig C has large break in skin that goes from the decomposed toes to halfway up the leg, skin around ankle is broken, unidentifiable parts of toe area have sunk to the bottom.
- No change with Pigs B and D.

- 45°F outside temperature.
- 3:30 P.M.

March 12, 2018 Day 47

- Pig A had noticeable marbling and a large break in the skin between the two front toes, hair still present.
- Pig C foot completely unrecognizable, jelly consistency, bones are soft, gel-like solidified fat around breaks in skin, random strange round hemorrhaging on underside of leg.
- No change with Pig B.
- Pig D might be slightly bloated (hardly noticeable), slight odor.
- 53°F outside temperature.
- 2:00 P.M.

March 14, 2018 Day 49

- No change with Pig A.
- No change with Pig C.
- No change with Pigs B and D.
- 46°F outside temperature.
- 4:00 P.M.

March 16, 2018 Day 51

- No change with Pig A.
- No change with Pig C.
- No change with Pig B.
- There was a bug flying around and landing on Pig D, the warmer weather might bring insect activity.
- 52°F outside temperature.
- 12:30 P.M.

March 18, 2018 Day 53

- No change with Pig A, still completely recognizable as a pig leg.
- The hemorrhage spots on Pig C have now turned purple in color (they were bright red when I first noticed them), lots of detached parts of the leg floating, film of fat seems to have mostly dissolved.
- No change with Pigs B and D.
- 36°F outside temperature.
- 1:00 P.M.

March 20, 2018 Day 55

- No change with Pig A.
- More detached parts of Pig C are floating and settled on the bottom, foot is nearly all decomposed.
- No change with Pigs B and D.
- 45°F outside temperature.
- 2:00 P.M.

March 22, 2018 Day 57

- No change with Pig A.
- More detached parts of Pig C are floating, foot is totally decomposed.
- No change with Pigs B and D.
- 54°F outside temperature.
- 3:30 P.M.

March 25, 2018 Day 60

- Study is concluded and specimens are disposed of after analyses and photographs.
- There was no further change with Pig A. It white in color, hair and nails were still present, the exposed muscle had disintegrated and only solidified fat was left, it expanded in size.
- Pig C had continued to disintegrate, foot was in chunks, exposed muscle had dissolved, solidified fat remained, bones were extremely soft (I could squeeze them flat), I separated the largest tissue that still remained to pry out tibia and fibula for testing.
- No further change with Pig B and Pig D, I unburied them for medial and lateral photos, extreme staining on both pigs, they had both shrunk in size, probably due to dryness, exposed muscle was still soft to the touch.
- 42°F outside temperature.
- 1:00 P.M. – 3:00 P.M.